COMBINED OBSERVATIONS OF THE ANOMALIES IN THE STRATOSPHERIC OZONE WITH THE SIBERIAN LIDAR STATION (SLS, 56.5°N, 85°E)

V.V. Zuev and S.V. Smirnov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received July 29, 1997

We discuss here some anomalies in the stratospheric ozone as revealed from simultaneous observations of the total ozone content (TOC) with a routine standard ozonometric measurements and from lidar measurements of the ozone and temperature profiles acquired with the Siberian Lidar Station in Tomsk. Five periods of 6 to 12-day duration have been isolated from the observational data series since 1994 and until 1997 when the ozone behavior exhibited anomalous features so that the deviations of TOC values averaged over 6 days exceeded 20% against the annual mean level of TOC. Negative anomalies were observed in January, 1994, and February, 1995; positive anomalies – in December, 1994 and November–December, 1996. The synoptic analysis has shown that the positive ozone anomalies were related to a front of a high stationary central cyclone that moved to lower latitudes. Similarly, negative ozone anomalies were referred to a front part of a high blocking anticyclone (high ridge) moved to higher latitudes. During the periods of ozone anomalies planetary waves with the wave number of 3 or 4 were observed in the tropospheric circulation and duration and the intensity of the ozone anomalies grew with the decreasing wave number. The analysis has shown that the main cause of such anomalous deviations in the total ozone content is a horizontal transport of the air mass caused by movement of high extensive pressure fields. The maximum local anomalies are related to zones of intense regular vertical motions in the low stratosphere above the tropospheric pressure field formations which accompany local changes in the geopotential magnitude being located in the contrast front parts of the pressure field formations.

INTRODUCTION

Significant variations in the total ozone content (TOC) observed in recent years in the midlatitudes of the Northern hemisphere attract interest in the mechanisms of such an ozone behavior.

Recent investigations[1–9] showed that the cause of negative anomalous deviations of TOC during winter and spring are both global changes of the general atmospheric circulation (GAC) regime[3,7,8] and possible intense catalytic destruction of the ozone molecules in the reaction of interaction with the free chlorine molecules originating from chlorine containing compounds.

The enhanced concentrations of which were also recorded during these periods.[1,2,9] However, there is no any idea yet, about what processes (photochemical or dynamical) dominate in these events.

Usually investigations deal with the cases or periods when negative deviations of TOC occur, because they are more important for mankind and biosphere in general, since only the ozone layer is the effective natural biological shield against the UV solar radiation. However, for a more comprehensive understanding the mechanisms causing the negative anomalies, it is necessary to elucidate what are the mechanisms of any, both positive and negative, deviations of TOC.

In this paper we present some results of combined observations of the ozone anomalies which were revealed from regular ozonometric measurements of the total ozone content (TOC) and lidar profiling of the stratospheric ozone and temperature performed at the SLS,[19] in Tomsk.

RESULTS OF OBSERVATIONS AND DISCUSSION

The total ozone content was measured using a standard technique by means of the M-124 No. 249 calibrated ozonometer. The measurement and TOC calculation processes[10] were partially automated in order to reach higher relative accuracy and the rate of

0235-6880/97/12 874-11 $02.00

measurements. The results of first observations were published in Ref. 11.

To date the time series contains more than 1000 diurnal mean values of TOC. The behavior of TOC since the beginning of 1994 till May 1997 is shown in Fig. 1. The data of 1993 are not presented because of irregular observations. To remove the periodic oscillations in the temporal behavior of TOC, we consider only the TOC deviations instead of its absolute values. The nonuniform series shown in Fig. 1 were transformed to the uniform one by means of linear interpolation. Then the statistically averaged annual behavior of the daily mean values of TOC was calculated, and the relative deviations from this annual series were calculated. They are shown in Fig. 2.

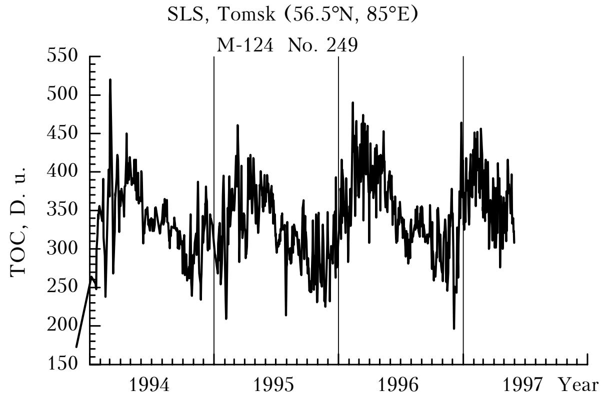


FIG. 1. Temporal behavior of the mean TOC from the data of ozonometric measurements in Tomsk.

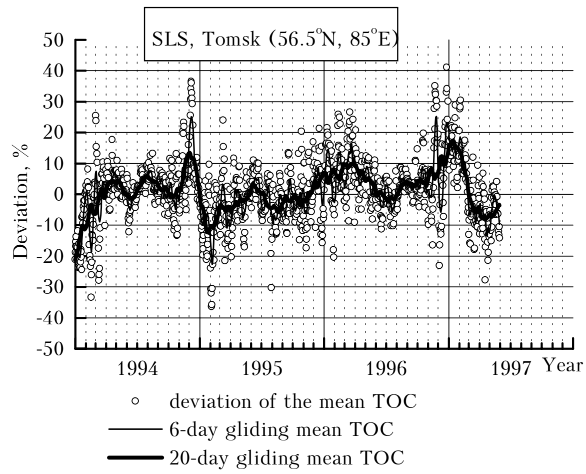


FIG. 2. Deviations of the daily mean TOC values from the statistically annual mean behavior.

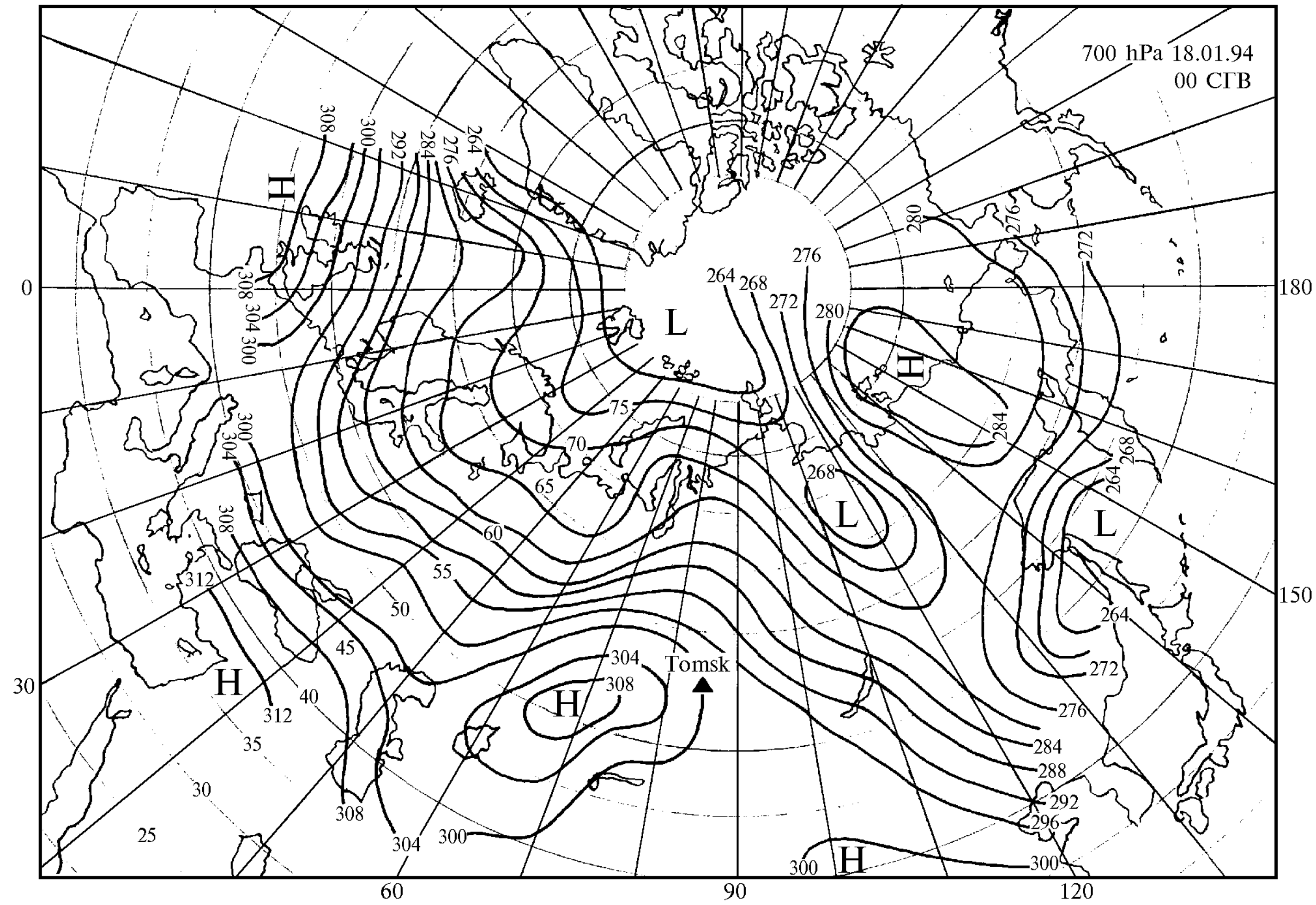
It is known since the first Dobson's publications[12,13] and from modern investigations[3,4,14,15] that ozone in troposphere and lower stratosphere, including the altitude of the climatic ozone maximum, is subject to a significant dynamic effect of circulation processes. To smoothen the mesoscale and synoptic oscillations, the 6-day averaging was done corresponding to the mean duration of a natural synoptic period. The 20-day averaging corresponding to the mean period of the long planetary waves, well reveals the GAC peculiarities and thus explicitly shows the periods with stable breaks of the normal time distribution.

The 20-day gliding average curve in Fig. 2 shows that the stable periods with both positive and negative deviations were observed in the TOC oscillations during the temporal interval under consideration. It is seen that the positive deviations dominated during 1994, except for winter, negative deviations dominated in 1995, and again positive were dominant in 1996. The period of significant positive deviations was observed in winter 1997, and negative ones were observed in spring. One may see from these data two particular intervals, the first is in the fall of 1994 and winter (1994–1995), and the second one is in winter 1996–1997 and spring 1997. Both intervals are characterized by the periods of high positive and then negative deviations with a sharp transition between them. Such, a nonperiodic, if strictly speaking, alternation of the deviations and parts with a sharp transitions, the interval between which is about 26 month, is probably related to the quasi-two-year circulation (QTYC) of the equatorial stratospheric circulation. According to the results from Ref. 16, the parts of a sharp transitions observed should correspond to the eastern phase of QTYC in the period of change of the air mass transfer direction from westward to eastward. In this connection, one can expect that the behavior of TOC in the second half of 1997 will be similar to that in 1995, i.e. the oscillations with insignificant amplitude of positive deviations in June and July and negative in August and September will be observed.

We have considered the 6-day gliding average curve shown in Fig. 2, which presents smoothened oscillations of the synoptic scale as well as the data dispersion caused by the error of measurements (the mean relative error is about 3%, the maximum error under unfavorable conditions of observations is up to 8%), as the initial for revealing the anomalous periods. The 20% deviation level was accepted as a criterion of the anomalous behavior. Thus, five parts were determined in the period analyzed since January 1994 till May 1997. They are presented in Table I.

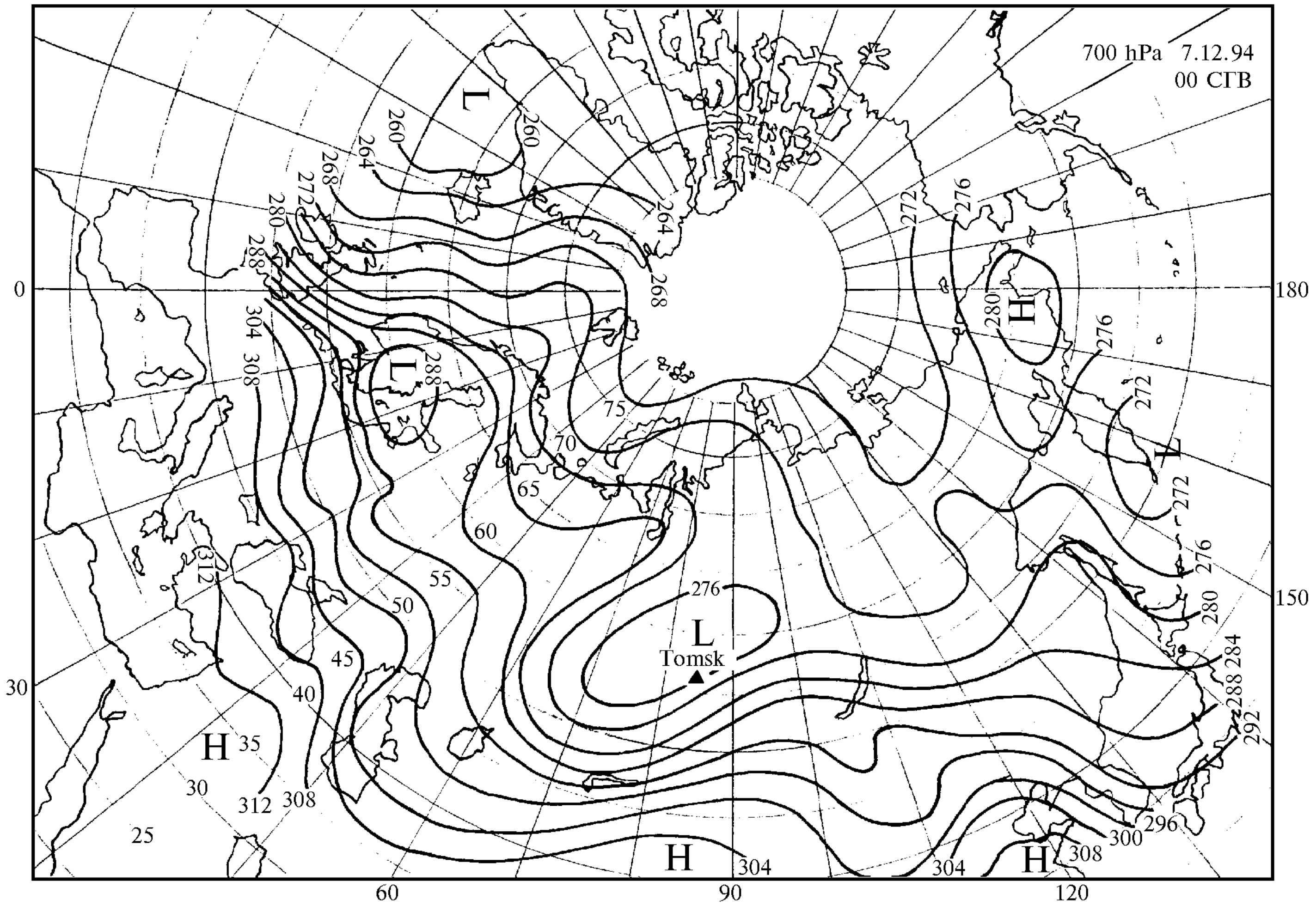
TABLE I. Periods of TOC deviations exceeding 20% *during the period since January 1994 till May 1997 in Tomsk.*

Period	Maximum deviation, %
January 11–20, 1994	−20.57
December 3–14, 1994	+25.05
February 3–8, 1995	−22.68
November 21–28, 1996	+25.16
December 24, 1996 – January 2, 1997	+23.10



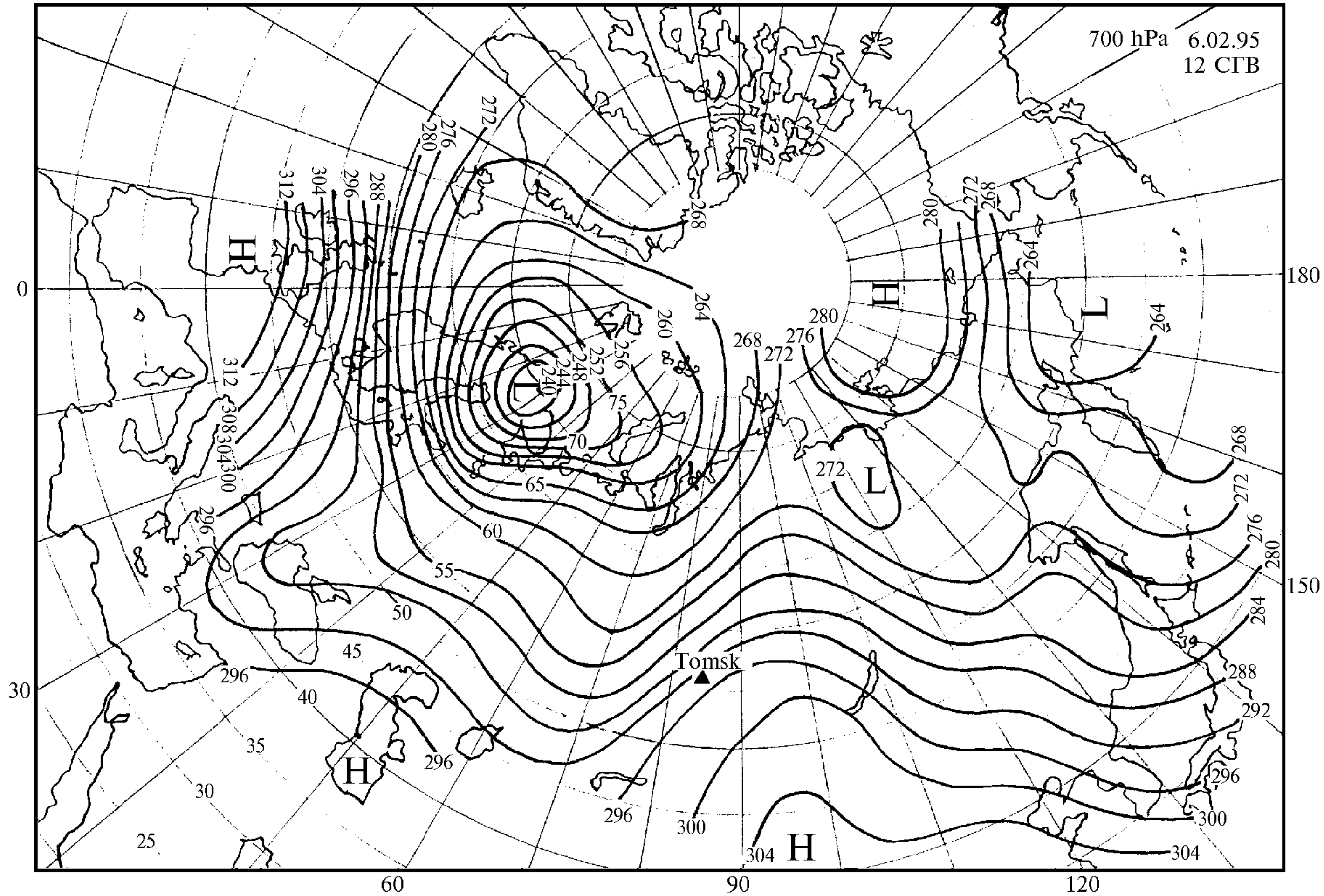
a

FIG. 3. Characteristic pressure fields at the level of 700 hPa *during the periods of anomalous deviations of TOC over Tomsk in 1994–1997.*



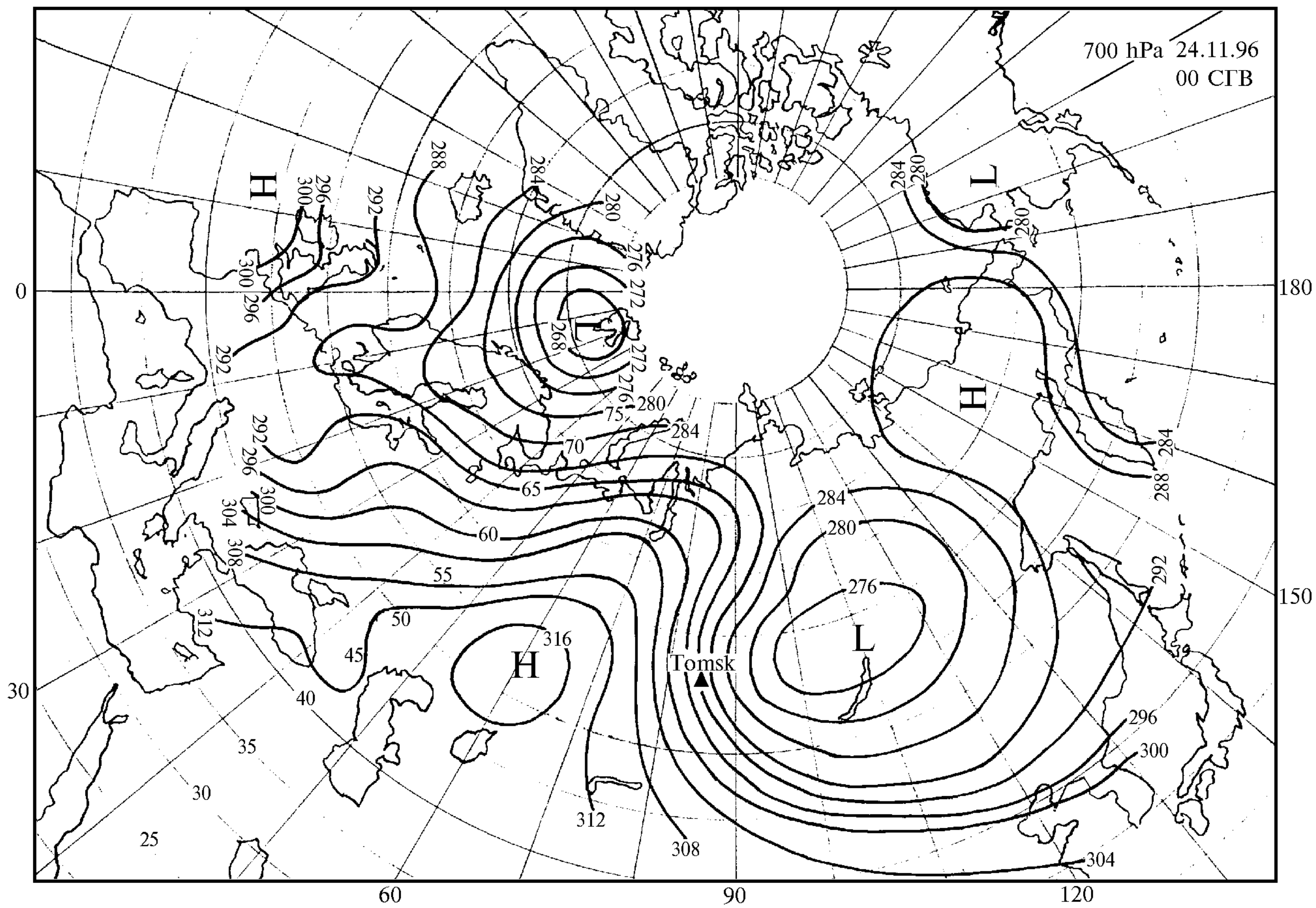
b

FIG. 3 (continued).



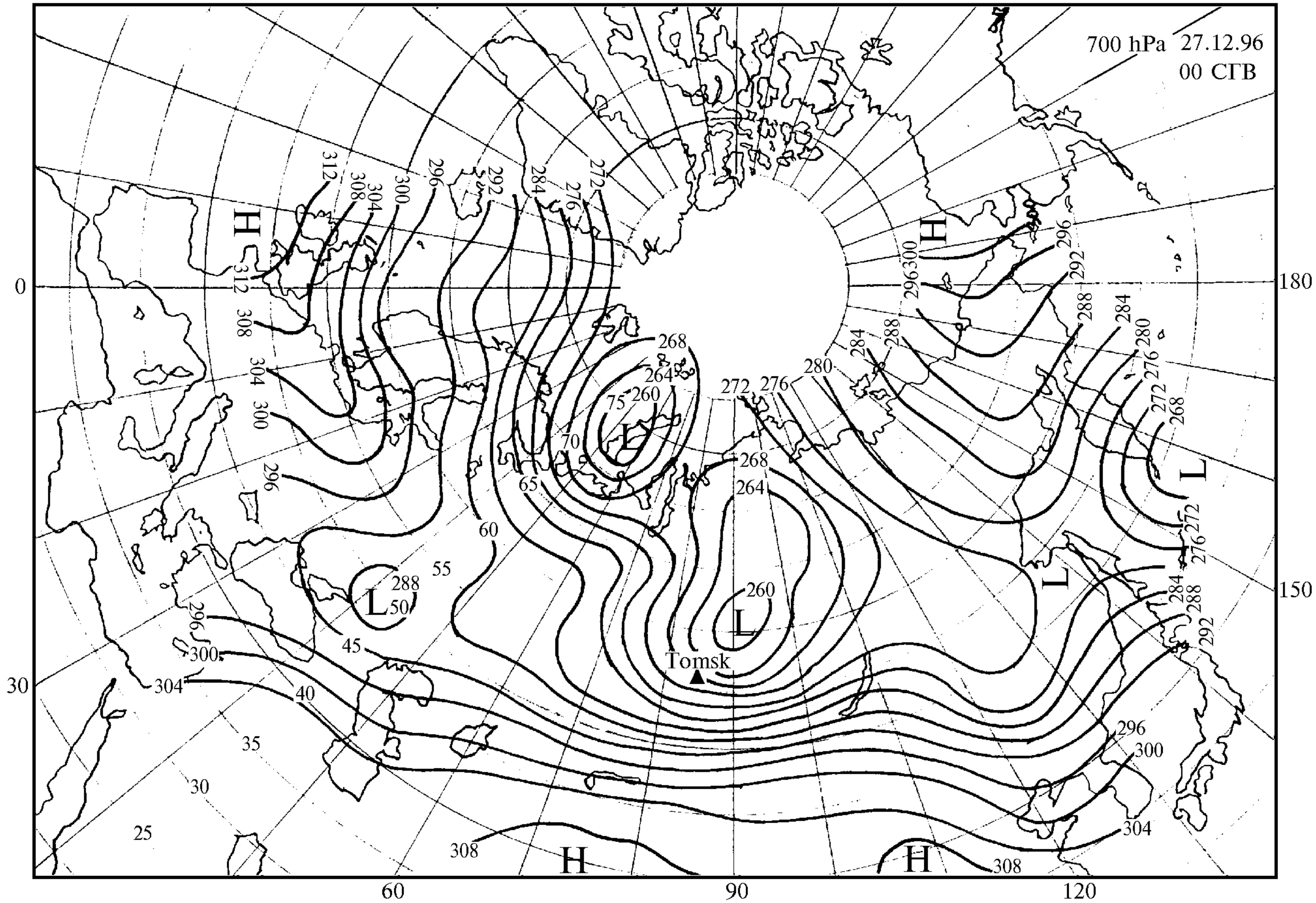
c

FIG. 3 (continued).



d

FIG. 3 (continued).



e

FIG. 3 (continued).

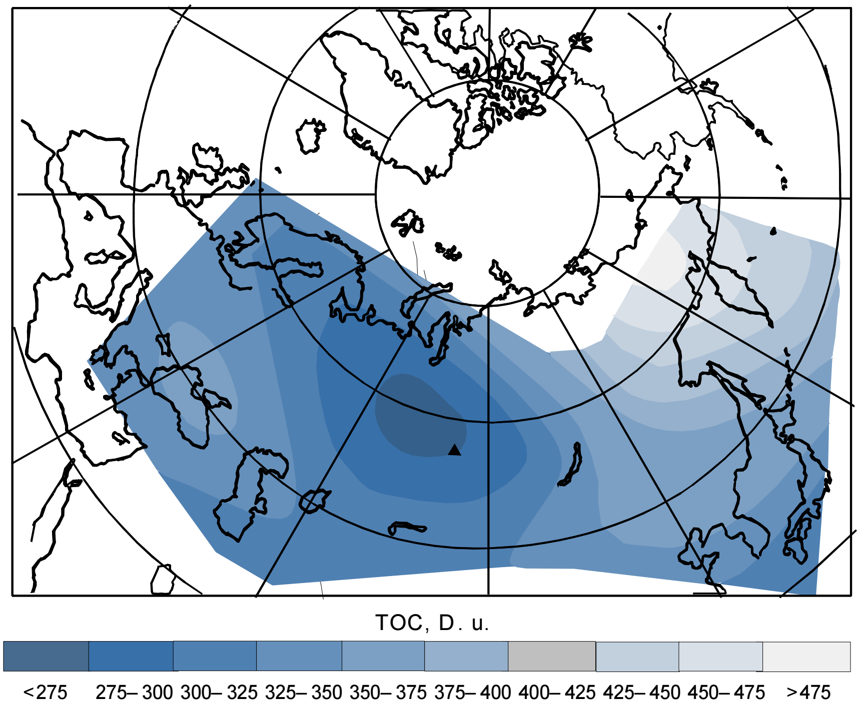


FIG. 4. TOC field reconstructed from the data of satellite observations at the beginning of the period of anomalously low TOC over Western and Eastern Siberia in February 1995.

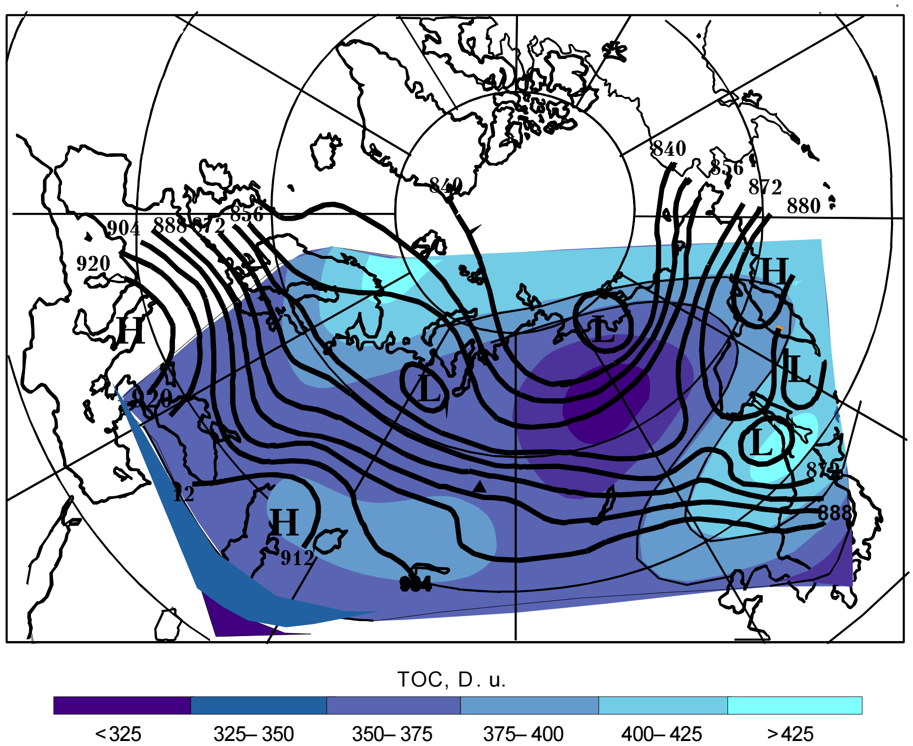


FIG. 5. TOC and pressure fields at the level of 300 hPa *at the end of the period of anomalously low TOC over Western and Eastern Siberia in February 1995.*

According to the periods of anomalous deviations of TOC, we considered analogous time intervals in the evolution of temperature and pressure fields as well as the available data of the lidar sounding of ozone and temperature. Unfortunately, because of the absence of the map of the baric topography at different altitudes, we were forced to consider only the levels below 500 hPa. In spite of this fact, these data were quite sufficient for a correct interpretation of the vertical structure and evolution of the high pressure field formations and for revealing their relation to the ozone anomalies.

The pressure fields at the level of 700 hPa are shown in Fig. 3. On the average they characterize the situations when the ozone anomalies were observed. It is well seen that in all cases the pressure field over the observation site (OS) had high gradient, zonal flow is significantly deformed by the low movable central cyclone displaced to the low latitudes or by the high blocking anticyclone displaced to the high latitudes.

Planetary waves with the wave numbers 3 or 4 are observed in all cases of the tropospheric circulation. The less is the wave number, and the more expanded are the central pressure field formations, the more significant are the intensity and duration of the ozone anomaly (the positive anomalies in December 1994 and 1996, and the negative one in February 1995).

It is also seen from Fig. 3 that the anticyclonic synoptic conditions (Fig. 3*a*, *c*), in which the OS is situated to the right of the planetary altitude frontal zone (PAFZ) in the area of the divergence of the anticyclonic curved isohypses, correspond to the periods of negative ozone anomalies. Cyclonic synoptic conditions (Fig. 3*b*, *d*, *e*), in which the OS is situated to the left of the PAFZ (or in it) in the area of convergence of the cyclonic curved isohypses correspond to the periods of positive ozone anomalies.

A significant decrease in TOC observed over Tomsk during first half of February 1995 is a particular case of the general depression of the ozone layer occurred in January and February over big area covering Western and Eastern Siberia. Evolution of this depression is illustrated in Figs. 4 and 5 where it is seen how it moved and transformed. The period of the maximum decrease of TOC over Tomsk corresponded to the period of core depression the being just over the city.

Superposition of the altitude pressure field and TOC field (Fig. 5) shows that the area of the minimum TOC is at the edge of the stratospheric circumpolar cyclonic vortex displaced to the lower latitudes from its usual position over Arctic. The warm pressure ridge in the troposphere corresponded to this situation, and the anomalously low values of temperature were observed in the lower stratosphere at the edge of the vortex. Figure 6 shows the temperature values at the standard isobaric levels, the TOC values and its deviations from the monthly mean values observed in the end of January 1995, before the period of maximum decrease in TOC over Tomsk in the first half of February.

Figure 6 also shows the vertical profiles of the scattering ratio obtained with a lidar during the same period, as well as the background profile obtained in September 1994 for a comparison. Significant increase of the aerosol scattering in the lower stratosphere well evidences the presence of aerosol formations of the type of the polar stratospheric clouds (PSC) characteristic of a very cold lower stratosphere during a polar winter.

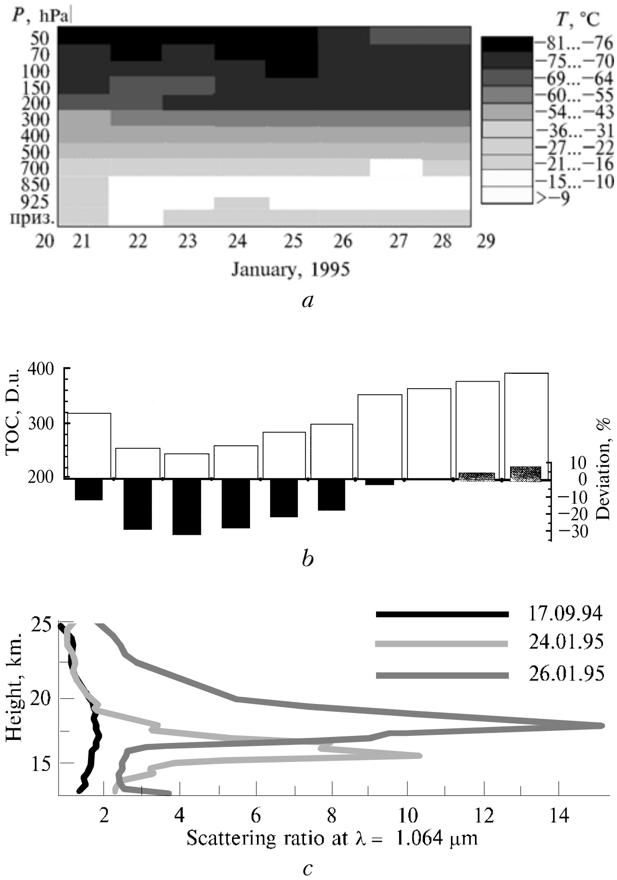


FIG. 6. Distribution of temperature (a), values and deviations of TOC (b) and the lidar profiles of the scattering ratio at the wavelength of 1064 nm *(c) at the end of January 1995.*

One may consider the dynamics of the TOC field depending on evolution of the synoptic formations in more detail using the results of complex measurements under the SATOR Program[17] carried out in summer 1995. Although no anomalous deviations were observed in this period, as is seen in Fig. 2, the development of the process is similar to the development of the ozone anomalies in winter 1994–1995, but with lower amplitudes. The deviations of the daily mean values TOC in the period of complex observations in June and July 1995 from the monthly mean values, as well as the indices of zonal and meridional circulation are shown in Fig. 7. The indices characterize the intensity of circulation components and the type of circulation processes. The indices were calculated by the Katz technique using the AT_{300} map for the area between 60 and 100°E and between 45 and 60°N.

It is seen from Fig. 7 that the enhanced values of the index of zonal component of the atmospheric transfer and the indices of meridional circulation of the Southern hemisphere correspond to the positive deviations of TOC, and the lower values of zonal circulation and the indices of meridional circulation of the Northern hemisphere correspond to the period of negative deviations of TOC in the first half of July 1995.

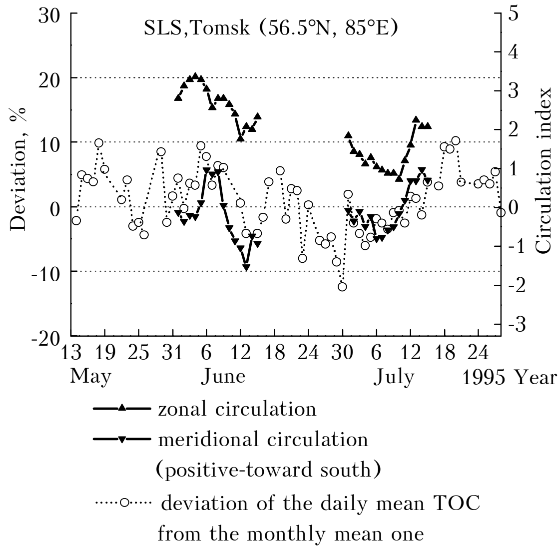


FIG. 7. Deviations of daily mean TOC values from the monthly mean one, and the indices of zonal and meridional circulation at the level of 300 hPa *in summer 1995.*

From the first sight there seems to be a contradiction between the increase of TOC and intensification of the southern meridional component of the atmospheric transfer, as well as between the decrease of TOC and the intensification of the northern component, because, according to the latitude distribution of TOC the inverse process should take place in these cases. So some researchers (see, for example, Refs. 1 and 2) conclude that an additional mechanism of ozone sink, including photochemical one, exists in these situations. However, there is no contradiction here. Indeed, the main local change of the TOC field, which have, on average, zonal distribution, occurs at the advection of air masses related to the migrating waves, which break the zonal behavior, along a PAFZ, so the ozone content increases in the altitude pressure troughs directed from north to south, and decreases in the ridges directed from south to north. But as the atmospheric motion is vortex and divergent, then[18] the visible meridional transfer is compensated for by the vortex (or quasidiffuse) transfer. As a consequence, the real transfer of conservative admixtures determined as the transfer of the mean meridional (or "residue") circulation, is the sum of the apparent meridional and vortex transfers. From this standpoint, the local change of TOC in the aforementioned cases shows not the apparent meridional circulation (i.e. the direction of the meridional component of the observed wind) but the result of the effect of the "residue" circulation. In this case the front part of the cyclone (altitude trough) and (or) back part of anticyclone (altitude ridge), to which corresponds the area of enhanced TOC and meridional south circulation component is the zone of convergence of air flows accompanied by the local decrease of geopotential, that causes the downward motion of the isobaric layer laying above, and then the layers of equal partial pressure of ozone (hence, the increase of TOC) and adiabatic heating. The greater is the density and cyclonic curvature of the isohypses, the stronger is the geopotential decrease and, hence, the greater is the TOC increase. Similarly, the back part of the cyclone (altitude trough) and (or) the front part of anticyclone, to which the area of lower TOC and the meridional north circulation component correspond, are the zones of divergence of air flows accompanied by the local increase of geopotential, that causes the upward motion of the isobaric layers laying above, and then the layers of equal partial pressure of ozone (hence, the decrease of TOC) and adiabatic pressure. Also, the greater is the density and anticyclonic curvature of isohypses, the greater is the geopotential increase and, hence, the stronger is the TOC decrease.

CONCLUSION

As follows from the ozonometric observations carried out at SLS, Tomsk during 1994–1997 five periods of 6 to 12 days duration were revealed in the temporal behavior of TOC with deviations preliminary averaged over 6 days, exceeding 20% against the annual mean series. The periods in January 1994 and February 1995 contained negative anomalies, and the periods in December 1994 and November and December 1996 contained the positive ones.

The analysis of the synoptic data corresponding to the periods of the ozone anomalies has shown that the positive ozone anomalies are related to the front part of a high slow moving central cyclone displaced to the lower latitudes. Analogously, the negative ozone anomalies may be referred to the front part of a high blocking anticyclone or a high ridge displaced to the higher latitudes.

The planetary waves with the wave numbers 3 or 4 were observed in the tropospheric circulation during the periods of ozone anomalies. The ozone anomaly duration increases as the wave number decreases.

As the analysis has shown, the main causes of the anomalous deviations in TOC field are the advective motions of air masses caused by the motion of the high expanded pressure field formations. The greatest local anomalous deviations are related to the zones of intense regular vertical motions in the lower stratosphere over the tropospheric pressure field formations, which accompany the local changes of geopotential and are located in the contrast front parts of the pressure field formations.

The conclusions are in a good agreement with the results from Refs. 3, 6, 7 and 14, which show that the cases with local anomalies of the TOC field has high correlation with the behavior of such atmospheric action centers as circumpolar cyclonic vortex and the seasonal Asian (Siberian) anticyclone. In turn, the motion and intensity of these pressure field formations are caused by changes in the regime of the general atmospheric circulation caused by the global climate changes.

ACKNOWLEDGMENTS

Authors would like to thank their colleagues from the Laboratory of Optical Weather for the synoptic data, and G.M. Kruchenitskii for the aerological data and maps of TOC.

The work was supported by Russian Foundation for Basic Researches (Grant No. 96–05–64282).

REFERENCES

1. R.D. Bozhkov, V.E. Fioletov, T.V. Kadygrova, et al., Meteorol. Gidrol., No. 9, 30–40 (1995).
2. V.M. Dorokhov, T.E. Potapova, F. Gutail, and J.-P. Pommero, Meteorol. Gidrol., No. 6, 53–62 (1996).
3. V.I. Bekoryukov, I.V. Bugaeva, G.R. Zakharov, et al., Meteorol. Gidrol., No. 7, 40–47 (1995).
4. K. Petzoldt, B. Naujokat, and K. Neugebohren, Geophys. Res. Lett. **21**, No. 13, 1203–1206 (1994).
5. C.E. Randall, D.W. Rusch, R.M. Bevilacqua, et al., Geophys. Res. Lett. **22**, No. 20, 2733–2736 (1995).
6. G.M. Kruchenitskii, V.I. Bekoryukov, V.M. Voloshchuk, et al., Atmos. Oceanic Opt. **9**, No. 9, 787–792 (1996)
7. V.I. Bekoryukov, I.V. Bugaeva, G.R. Zakharov, et al., Atmos. Oceanic Opt. **9**, No. 9, 793–796 (1996).
8. E.A. Zhadin, Meteorol. Gidrol., No. 7, 48–55 (1995).
9. E.V. Browell, C.F. Butler, S. Ismail, et al., Geophys. Res. Lett. **17**, No. 4, 325–328 (1990).
10. S.L. Bondarenko, V.L. Pravdin, and S.V. Smirnov, Pribory i Tekhnika Eksperimenta, No. 4, 167 (1996).
11. V.V. Zuev and S.V. Smirnov, Izv. RAN, Fizika Atmos. Okeana **32**, No. 4, 573–575 (1996).
12. G.M.B. Dobson, D.M. Harrison and J. Lawrence, Proc. R. Soc. Part III, No. A122 456–486 (London, 1929).
13. D. Dobson and A. Mitgem, in: *Some Problems of Modern Meteorology* (Gidrometeoizdat, Leningrad, 1937), pp. 137–154.
14. V.I. Bekoryukov, G.R. Zakharov, A.A. Kukoleva and V.E. Fioletov, Meteorol. Gidrol., No. 12, 103–105 (1990).
15. P. Milch and J. Lastovicka, Annales Geophysicae, No. 14, 744–752 (1996).
16. *Monitoring of the General Atmospheric Circulation. Trudy GMC*, issue 132 (Gidrometeoizdat, Sankt Petersburg, 1992), 94 pp.
17. V.V. Zuev, Atmos. Oceanic Opt. **5**, No. 6, 354–359 (1992).
18. G. Brasie and S. Solomon, *Aeronomy of the Middle Atmosphere* (Gidrometeoizdat, Leningrad, 1987), 414 pp.
19. V.V. Zuev. Atmos. Oceanic Opt. **9**, No. 9, 745–753 (1996).